US009209834B2

(12) **United States Patent**
Lee et al.

(10) **Patent No.: US 9,209,834 B2**
(45) **Date of Patent: Dec. 8, 2015**

(54) **SYMBOL MAPPING FOR BINARY CODING**

(71) Applicant: **BROADCOM CORPORATION**, Irvine, CA (US)

(72) Inventors: **Tak K. Lee**, Irvine, CA (US); **Ba-Zhong Shen**, Irvine, CA (US); **Kelly Brian Cameron**, Irvine, CA (US); **Hau Thien Tran**, Irvine, CA (US)

(73) Assignee: **Broadcom Corporation**, Irvine, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 184 days.

(21) Appl. No.: **13/907,737**

(22) Filed: **May 31, 2013**

(65) **Prior Publication Data**

US 2013/0332792 A1 Dec. 12, 2013

Related U.S. Application Data

(60) Provisional application No. 61/658,746, filed on Jun. 12, 2012, provisional application No. 61/818,485, filed on May 2, 2013.

(51) **Int. Cl.**

H03M 13/00	(2006.01)
G06F 11/00	(2006.01)
H03M 13/05	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H03M 13/05*** (2013.01); ***H04L 27/3438*** (2013.01); *H04L 27/362* (2013.01)

(58) **Field of Classification Search**

CPC ... H03M 13/255; H03M 13/47; H03M 13/05; H04L 27/3433; H04L 27/3438; H04L 27/3444

USPC 714/746, 752, 792, 800–801; 375/261–262, 265, 295

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,891,896	B1 *	5/2005	Betts	375/264
7,535,975	B1	5/2009	ten Brink et al.	
8,351,536	B2 *	1/2013	Mazet et al.	375/295

(Continued)

OTHER PUBLICATIONS

Gelblum et al., A forbidden Rate region for generalized cross constellations, 1997, IEEE Trans. on Info. Theory, vol. 43, No. 1, pp. 335-341.*

Les Brown Lantiq Germany; Revised Recommendation G.9960; TD, ITU-T Draft; Study Period 2009-2012; Dec. 22, 2011; pp. 1-181.

(Continued)

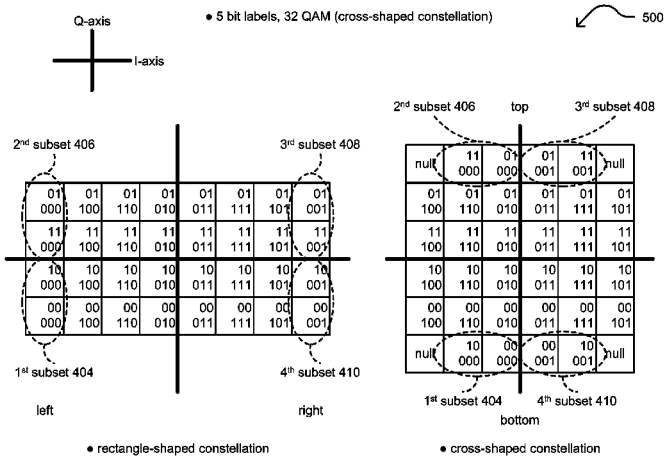
Primary Examiner — Shelly A Chase

(74) *Attorney, Agent, or Firm* — Garlick & Markison; Shayne X. Short

(57) **ABSTRACT**

The present disclosure presents symbol mapping for any desired error correction code (ECC) and/or uncoded modulation. A cross-shaped constellation is employed to perform symbol mapping. The cross-shaped constellation is generated from a rectangle-shaped constellation. Considering the rectangle-shaped constellation and its left hand side, a first constellation point subset located along that left hand side are moved to be along a top of the cross-shaped constellation while a second constellation point subset located along that left hand side are moved to be along a bottom of the cross-shaped constellation. For example, considering an embodiment having four constellation point subsets along the left hand side of the rectangle-shaped constellation, two of those subsets are moved to be along the top of the cross-shaped constellation while two other subsets of the constellation points along the left hand side are moved to be along the bottom of the cross-shaped constellation.

20 Claims, 9 Drawing Sheets



(51) **Int. Cl.**
H04L 27/34 (2006.01)
H04L 27/36 (2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2001/0017900	A1*	8/2001	Schelstraete	375/265
2002/0031190	A1	3/2002	Ophir et al.	
2002/0136318	A1*	9/2002	Gorokhov et al.	375/261
2011/0305300	A1	12/2011	Ko	

OTHER PUBLICATIONS

Smith; Odd-Bit Quadrature Amplitude-Shift Keying; IEEE Transactions on Communications; Mar. 1, 1975; pp. 385-389; vol. COM-23, No. 3.

Vitthaladevuni et al.; Exact BER Computation for Cross QAM Constellations; IEEE Transactions on Wireless Communications; Nov. 1, 2005; pp. 3039-3050; vol. 4, No. 6.

European Patent Office; EP Search Report; EP Application No. 13002914.3; Mar. 4, 2015; 3 pgs.

* cited by examiner

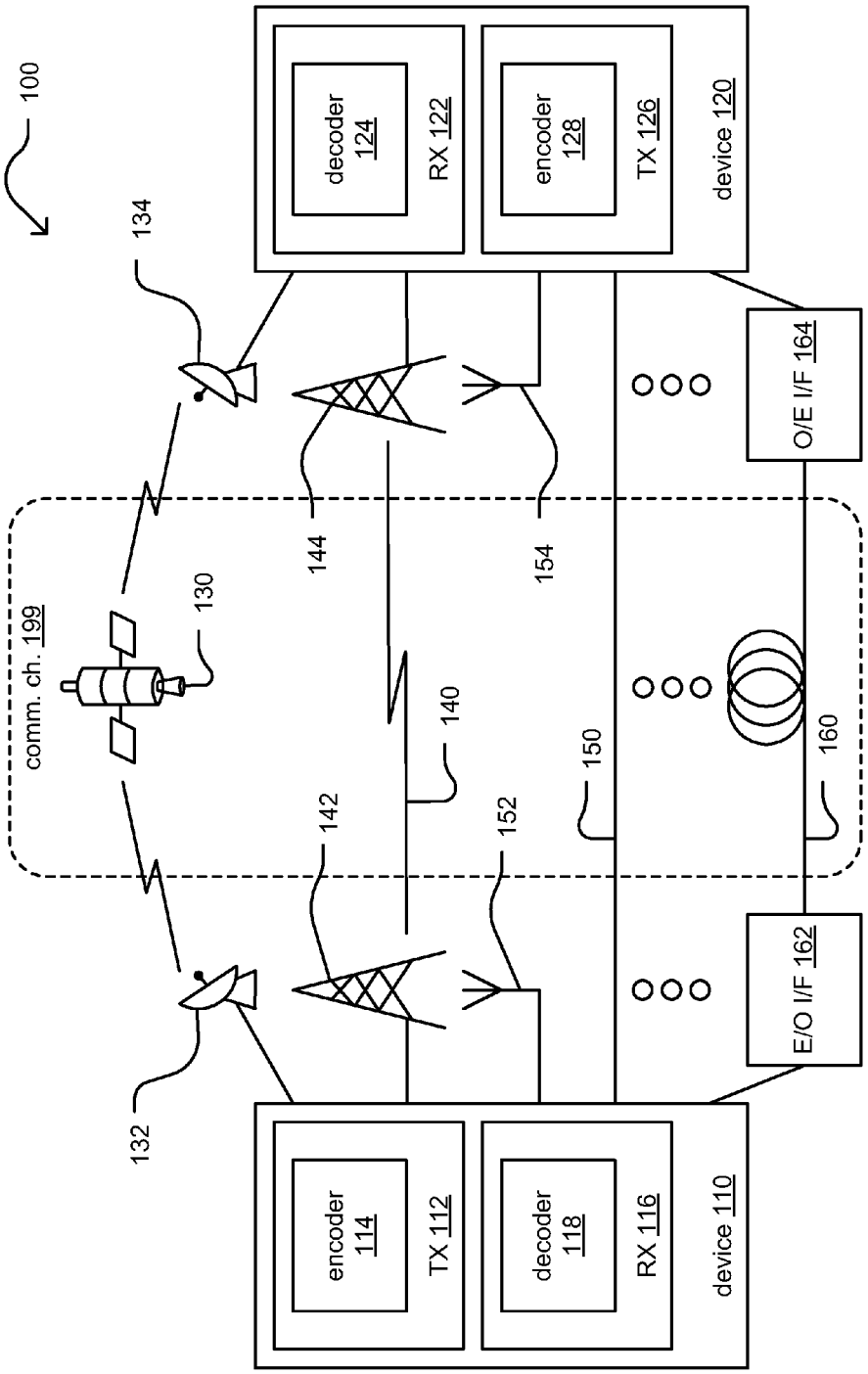

100
134
decoder 124
RX 122
encoder 128
TX 126
device 120
O/E I/F 164
144
154
comm. ch. 199
130
140
150
160
142
152
132
encoder 114
TX 112
decoder 118
RX 116
device 110
E/O I/F 162

FIG. 1

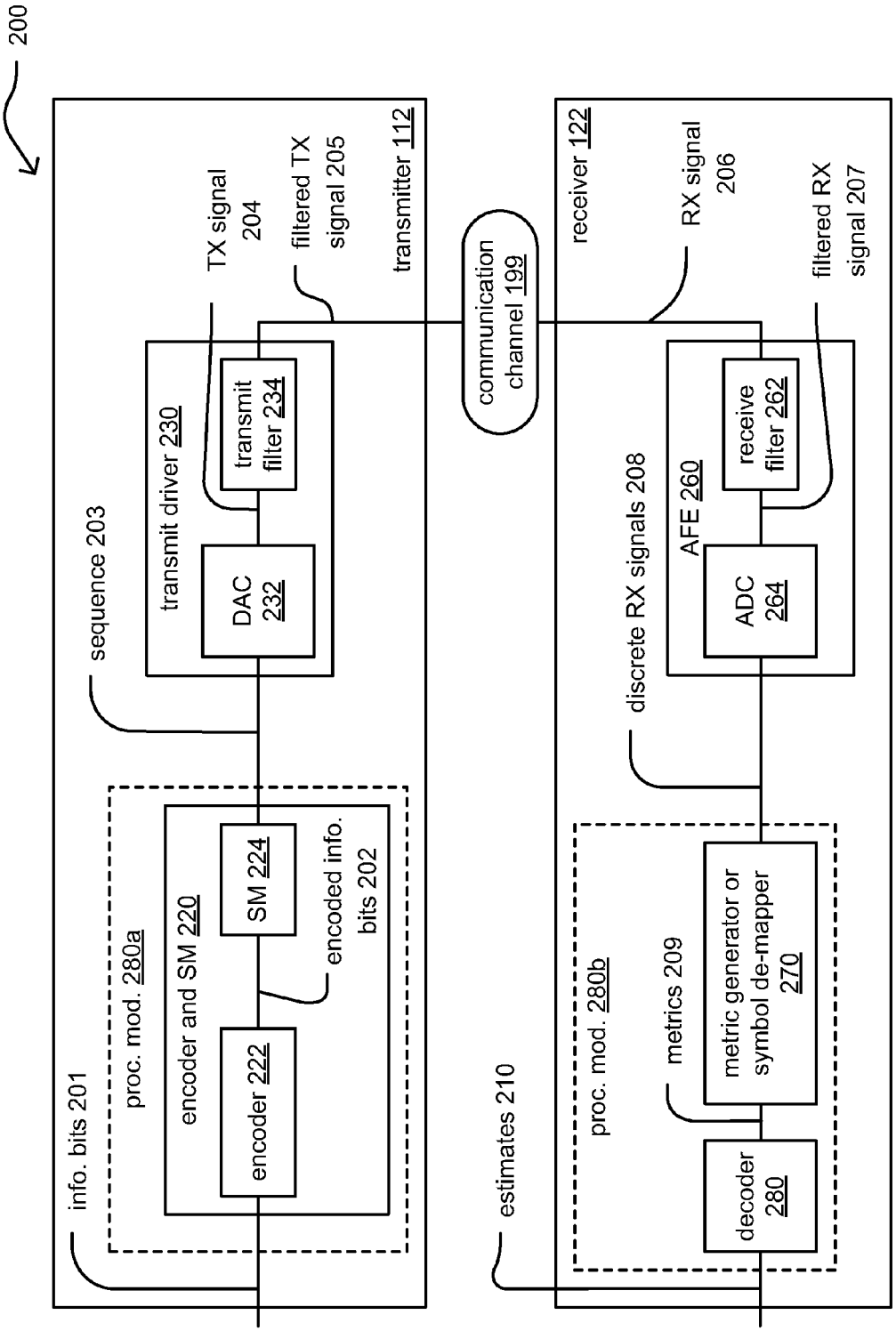

200
transmitter 112
receiver 122
info. bits 201
proc. mod. 280a
encoder and SM 220
encoder 222
SM 224
encoded info. bits 202
sequence 203
transmit driver 230
DAC 232
transmit filter 234
TX signal 204
filtered TX signal 205
communication channel 199
RX signal 206
filtered RX signal 207
AFE 260
receive filter 262
ADC 264
discrete RX signals 208
proc. mod. 280b
metrics 209
metric generator or symbol de-mapper 270
decoder 280
estimates 210

FIG. 2

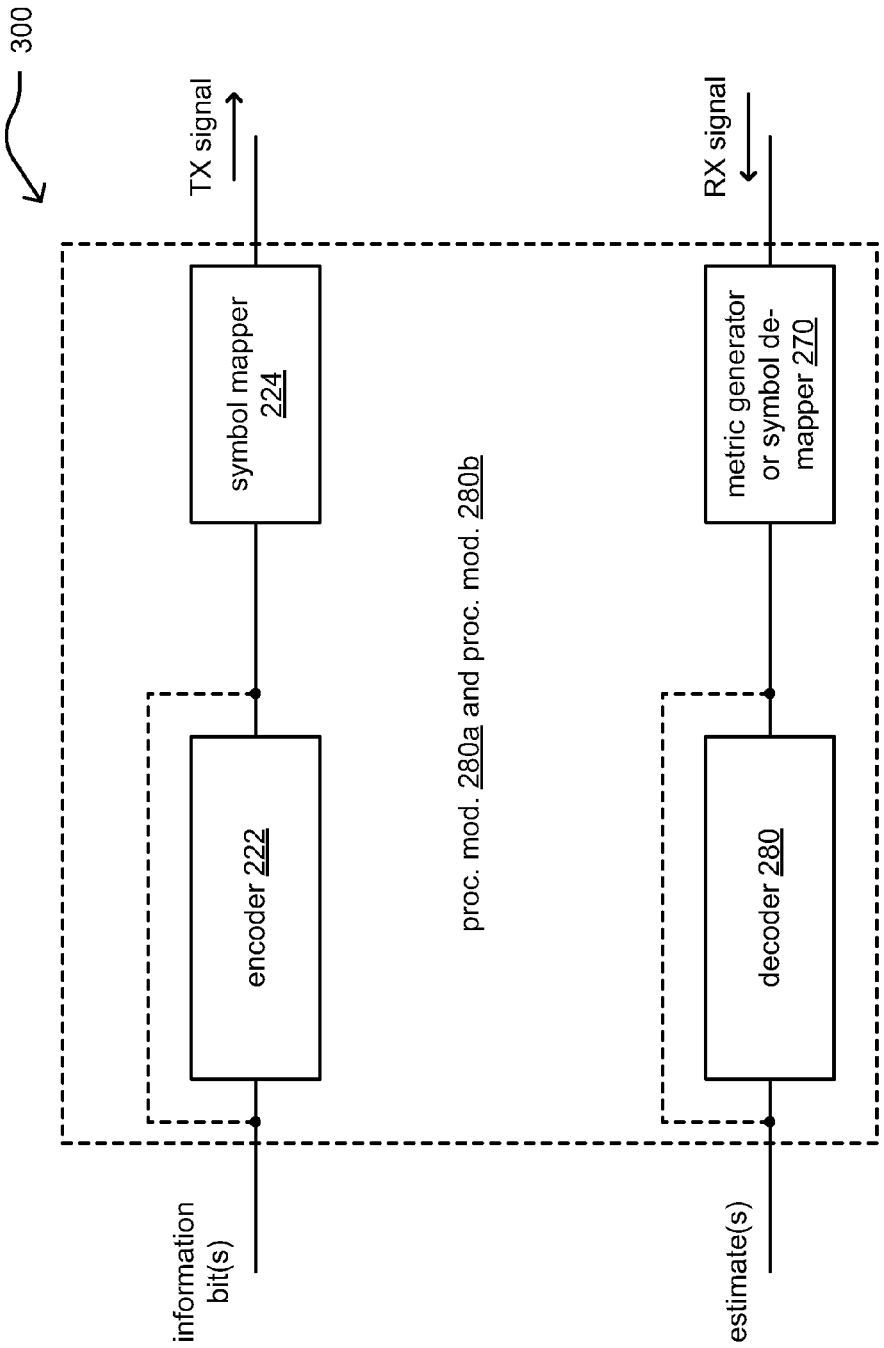

300
TX signal
RX signal
symbol mapper 224
metric generator or symbol de-mapper 270
proc. mod. 280a and proc. mod. 280b
encoder 222
decoder 280
information bit(s)
estimate(s)

FIG. 3

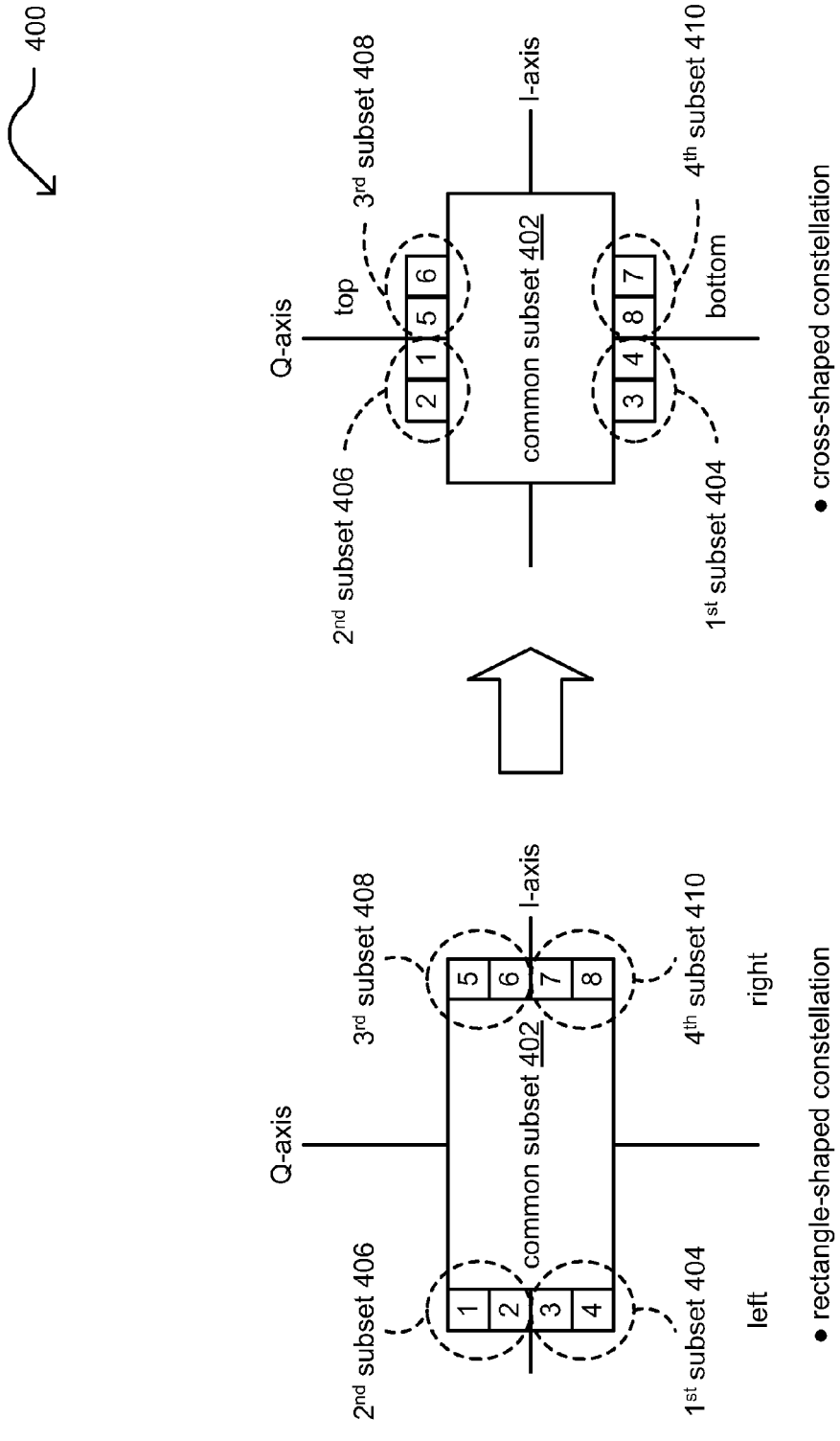

400
Q-axis
I-axis
common subset 402
2nd subset 406
3rd subset 408
1st subset 404
4th subset 410
top
bottom
left
right
1
2
3
4
5
6
7
8
• rectangle-shaped constellation
• cross-shaped constellation

FIG. 4

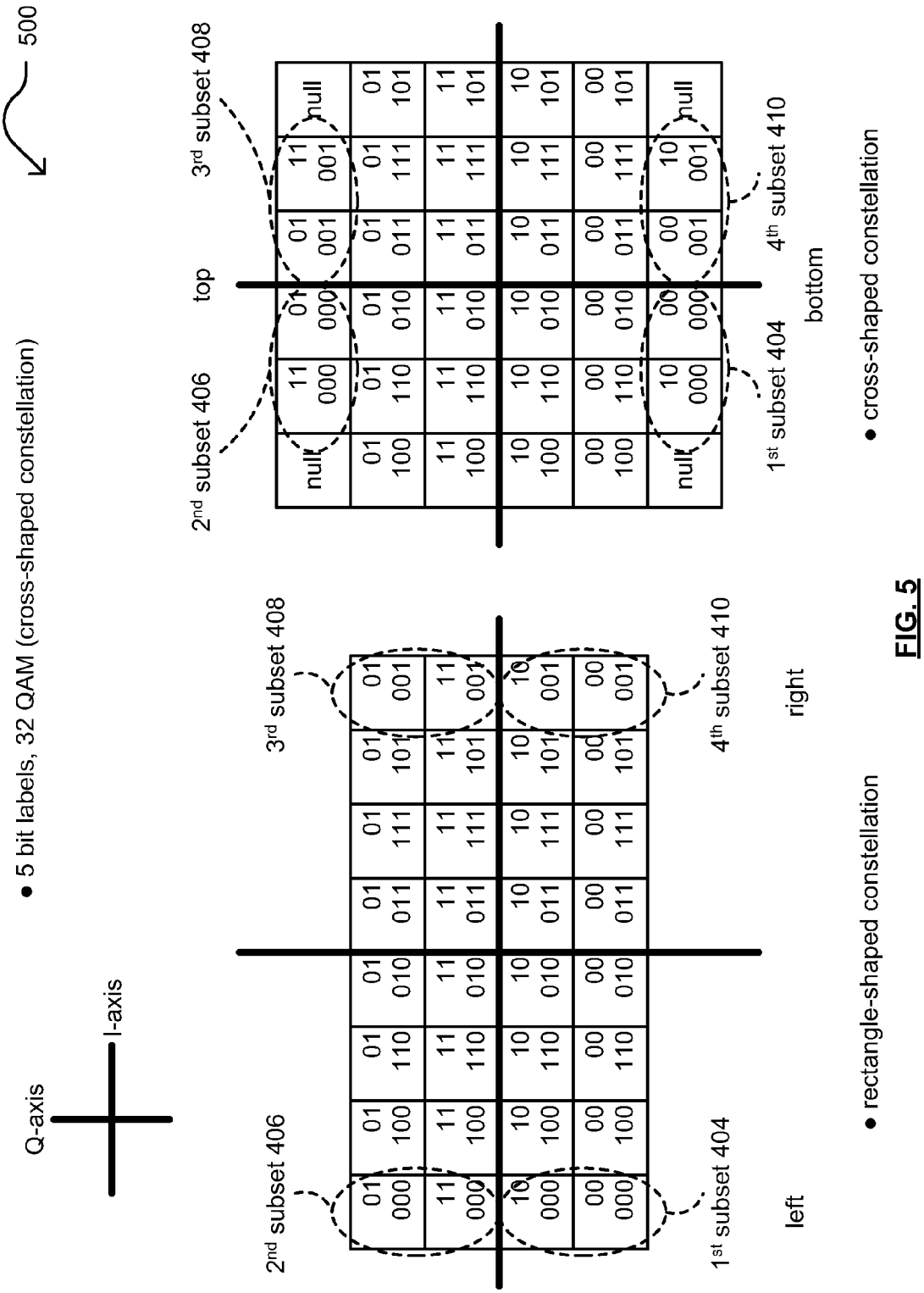
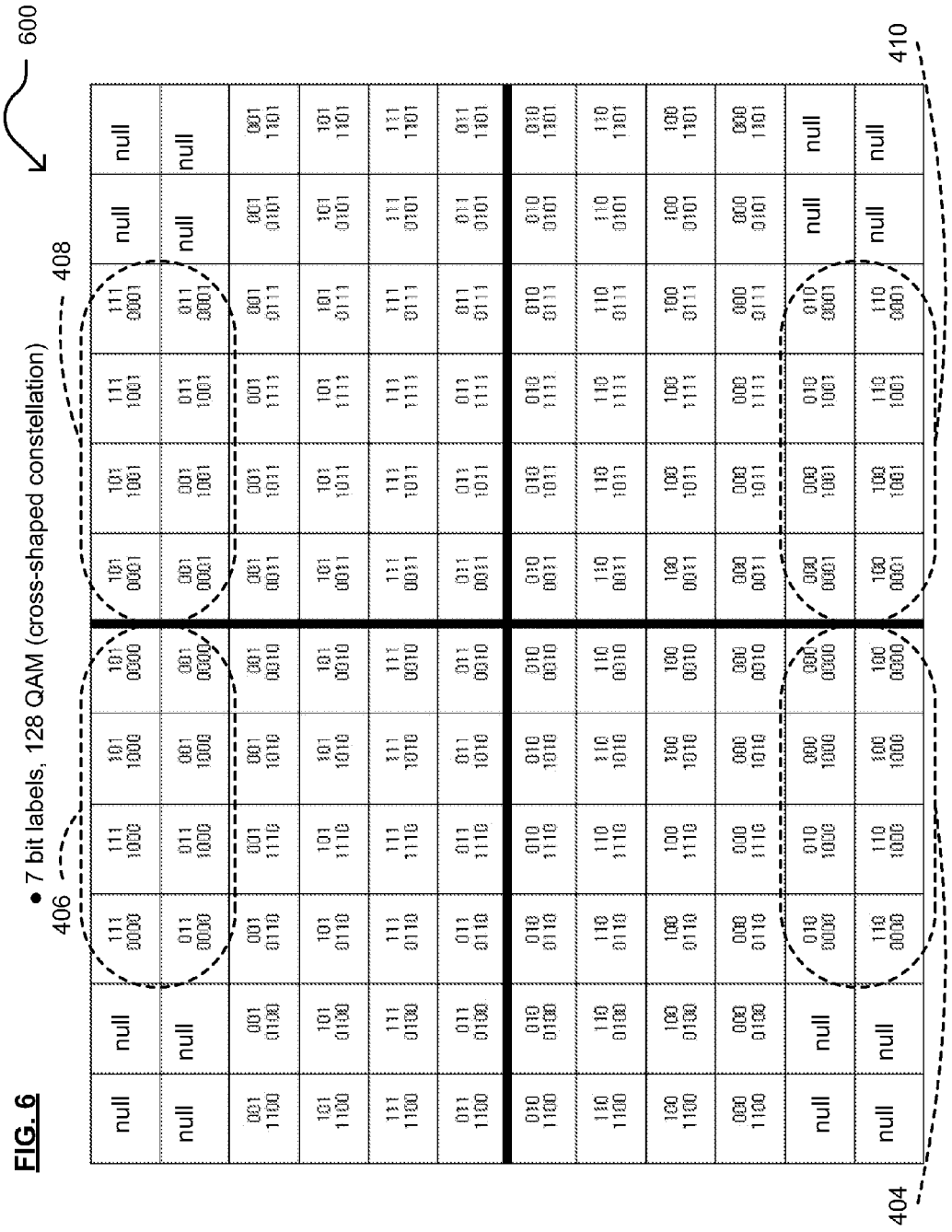

500
• 5 bit labels, 32 QAM (cross-shaped constellation)
Q-axis
I-axis
2nd subset 406
3rd subset 408
top
bottom
1st subset 404
4th subset 410
left
right
• rectangle-shaped constellation
• cross-shaped constellation

FIG. 5

FIG. 6


600
• 7 bit labels, 128 QAM (cross-shaped constellation)
406
408
404
410
null

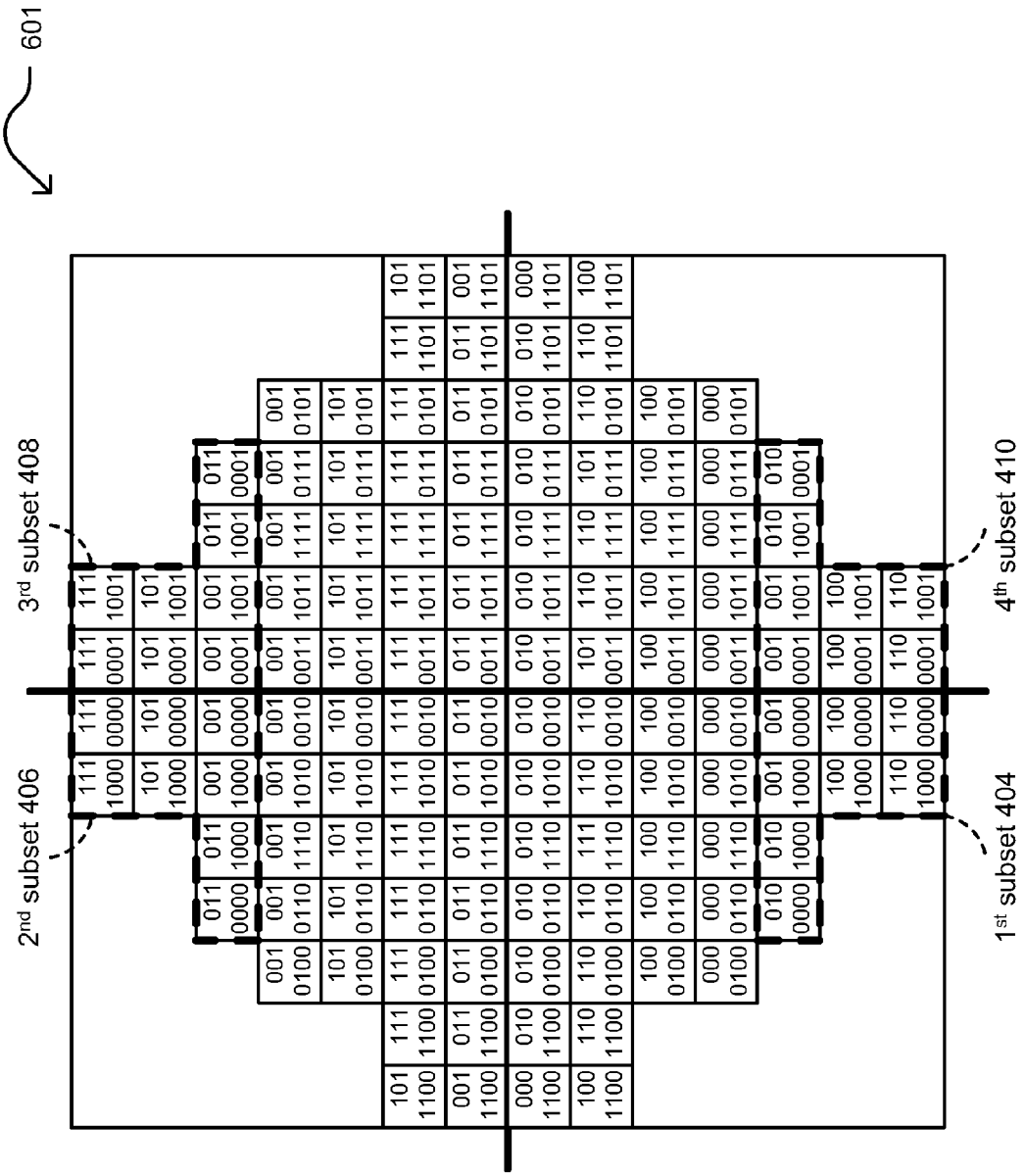

601
3rd subset 408
2nd subset 406
4th subset 410
1st subset 404

FIG. 6A

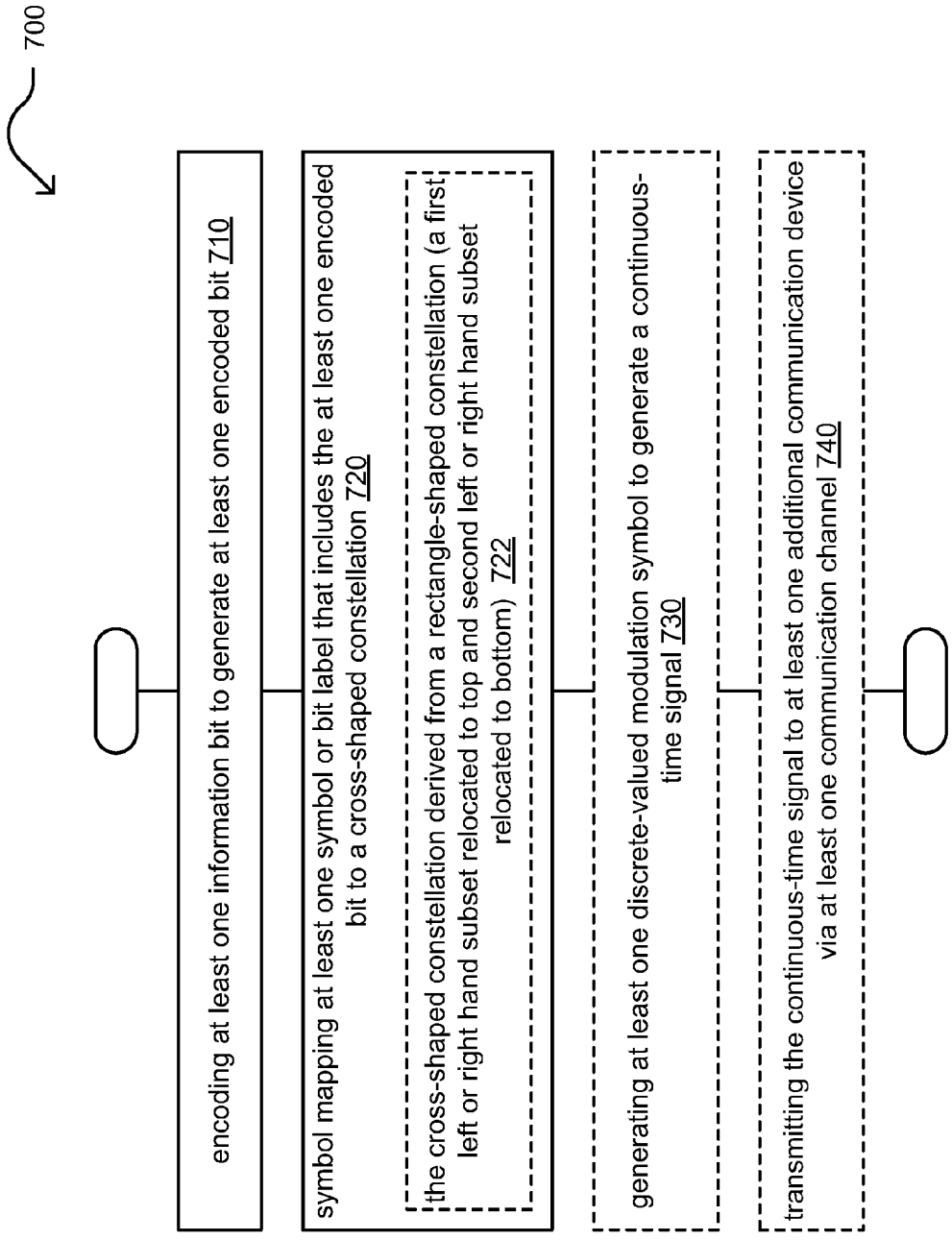

700
encoding at least one information bit to generate at least one encoded bit 710
symbol mapping at least one symbol or bit label that includes the at least one encoded bit to a cross-shaped constellation 720
the cross-shaped constellation derived from a rectangle-shaped constellation (a first left or right hand subset relocated to top and second left or right hand subset relocated to bottom) 722
generating at least one discrete-valued modulation symbol to generate a continuous-time signal 730
transmitting the continuous-time signal to at least one additional communication device via at least one communication channel 740

FIG. 7

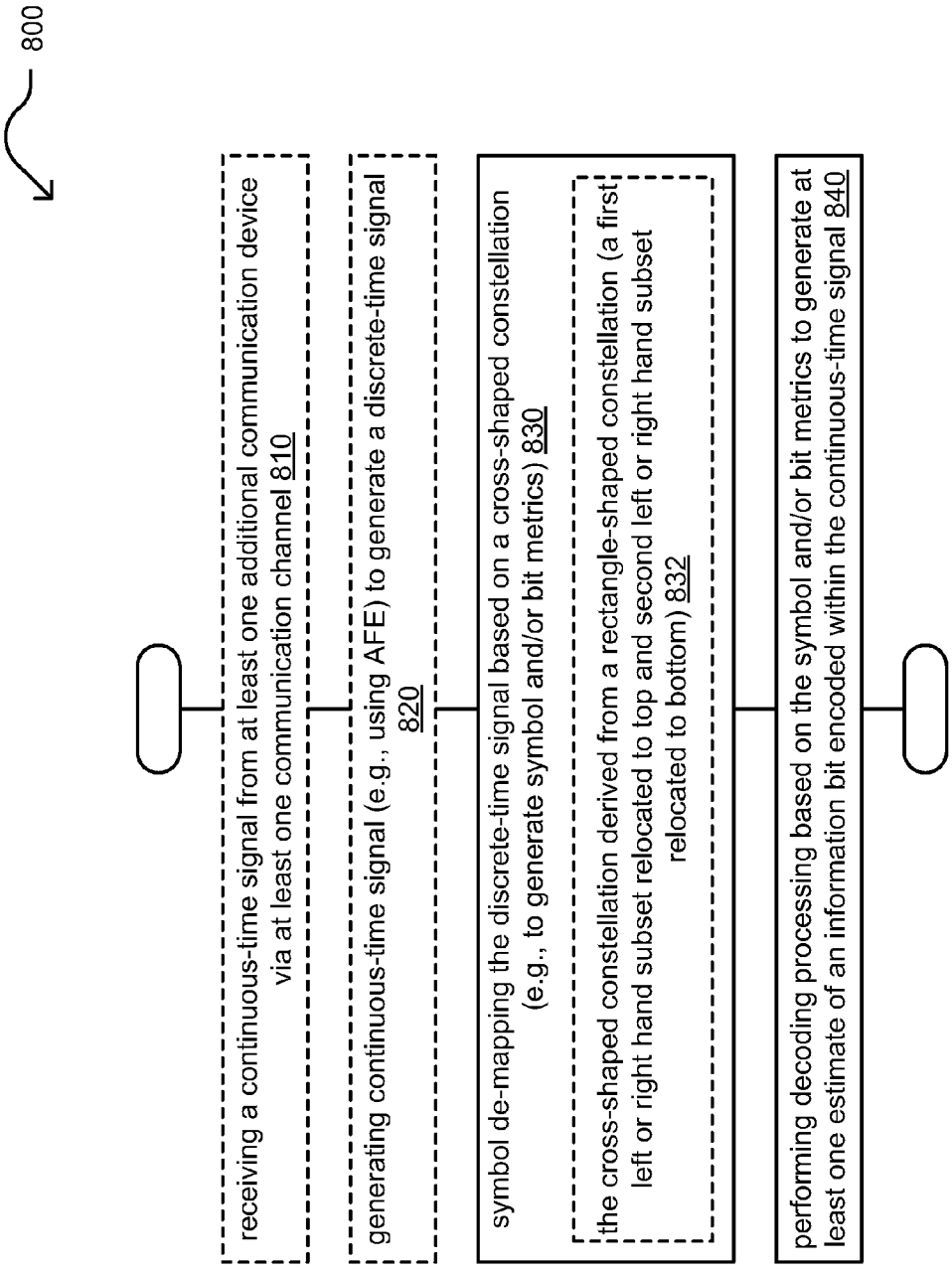

800
receiving a continuous-time signal from at least one additional communication device via at least one communication channel 810
generating continuous-time signal (e.g., using AFE) to generate a discrete-time signal 820
symbol de-mapping the discrete-time signal based on a cross-shaped constellation (e.g., to generate symbol and/or bit metrics) 830
the cross-shaped constellation derived from a rectangle-shaped constellation (a first left or right hand subset relocated to top and second left or right hand subset relocated to bottom) 832
performing decoding processing based on the symbol and/or bit metrics to generate at least one estimate of an information bit encoded within the continuous-time signal 840

FIG. 8

SYMBOL MAPPING FOR BINARY CODING

CROSS REFERENCE TO RELATED PATENTS/PATENT APPLICATIONS

Provisional Priority Claims

The present U.S. Utility Patent Application claims priority pursuant to 35 U.S.C. §119(e) to the following U.S. Provisional Patent Applications which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes:

1. U.S. Provisional Patent Application Ser. No. 61/658,746, entitled "Symbol mapping for binary coding," filed Jun. 12, 2012.

2. U.S. Provisional Patent Application Ser. No. 61/818,485, entitled "Symbol mapping for binary coding," filed May 2, 2013.

BACKGROUND

1. Technical Field

The present disclosure relates generally to communication systems; and, more particularly, to symbol mapping and/or symbol de-mapping (e.g., modulation and/or demodulation) within various communication devices operative within such communication systems.

2. Description of Related Art

Data communication systems have been under continual development for many years. One such type of communication system that has been of significant interest lately is a communication system that employs iterative error correction codes (ECCs). Communications systems with iterative codes are often able to achieve lower bit error rates (BER) than alternative codes for a given signal to noise ratio (SNR).

An ideal communication system design goal is to achieve Shannon's limit for a communication channel. Shannon's limit may be viewed as being the data rate to be used in a communication channel, having a particular SNR that achieves error free transmission through the communication channel. In other words, the Shannon limit is the theoretical bound for channel capacity for a given modulation and code rate.

Generally speaking, within the context of communication systems, there is a first communication device at one end of a communication channel with an ECC encoder and second communication device at the other end of the communication channel with an ECC decoder. In many instances, one or both of these two communication devices includes both the encoder and decoder (e.g., for bi-directional communications). The transmitter and receiver may use various forms of symbol mapping and/or modulation to generate symbols that carry more than one bit of information (e.g., associated with constellation points of the symbol mapping and/or modulation) to increase throughput of information within such communication systems.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** illustrates an embodiment of a communication system.

FIG. **2** illustrates an example of communication between two communication devices.

FIG. **3** illustrates embodiments of encoding and symbol mapping and symbol de-mapping and decoding.

FIG. **4** illustrates an embodiment of conceptually altering a rectangle shaped constellation to achieve a cross shaped constellation.

FIG. **5** illustrates an example of 32 QAM constellation in accordance with the present disclosure.

FIG. **6** illustrates an example of 128 QAM constellation in accordance with the present disclosure.

FIG. **6**A illustrates another example of a 128 QAM constellation in accordance with the present disclosure.

FIG. **7** is a diagram illustrating an embodiment of a method for operating one or more wireless communication devices.

FIG. **8** is a diagram illustrating another embodiment of a method for operating one or more wireless communication devices.

DETAILED DESCRIPTION

FIG. **1** illustrates an embodiment of a communication system **100**. The communication system **100** that includes communication devices **110** **120** (only two shown) and communication system infrastructure, which supports one or more wired or wireless communication channels **199**. The communication system infrastructure includes one or more of: a satellite **130** and corresponding dishes **132**, **134**; a wireless communication link **140** via wireless communication towers (e.g., base stations, access points, etc.) **142**, **144** and/or an antennas **152**, **154**; fiber optic equipment such as an optical communication link **160** via an electrical to optical (E/O) interface **162** and optical to electrical (O/E) interface **164**; and a wired communication link **150** (e.g., such as within a digital subscriber line (DSL) based system).

Each of the communication devices **110**, **120** may be stationary or mobile devices. For example, a mobile communication device **110** and **120** is one of a cellular telephone, a tablet, a laptop computer, a video game console, a remote controller, a multimedia (e.g., audio and/or video) player, etc. As another example, a stationary communication device is a device that, while it can be moved, is generally used at a fixed location such as a computer, an access point, etc.

Each of the communication devices includes a transmitter **112**, **126** and/or a receiver **116**, **122**. The transmitter **112**, **126** includes an encoder **114**, **128** and the receiver **116**, **122** includes a decoder **118**, **124**. The encoder **114**, **128** and the decoder **118**, **124** utilize a constellation map that includes a plurality of constellation points and null points arranged in one or more patterns that reduce transmission errors and/or lower SNR while achieving a desired BER of a communication channel. The constellation map will be described in greater detail with reference to one or more of the subsequent figures.

FIG. **2** illustrates an example **200** of communication between two communication devices. In this example, the transmitter **112** of one communication device **110** is transmitting a signal via the communication channel **199** to the receiver **122** of another communication device **120**. The transmitter **112** includes a processing module **280***a* and a transmit driver **230**. The processing module **280***a* is configured to include an encoder **222** (e.g., low density parity check (LDPC) coding, any other desired error correction code (ECC) such as turbo coding, convolutional coding, turbo trellis coded modulation (TTCM) coding, Reed-Solomon (RS) coding, BCH (Bose and Ray-Chaudhuri, and Hocquenghem) coding, etc. and/or uncoded modulation) and a symbol mapper (SM) **224** or configured to include a combined encoder and symbol mapper **220**. The transmit driver **230** includes a digital to analog converter (DAC) **232** and a transmit filter **234**. The receiver **122** includes a processing

module **280***b* and an analog front end (AFE) **260**. The processing module **280***b* is configured to include a decoder **280** and a metric generator or symbol de-mapper **270**. The AFE **260** includes a receive filter **262** and an analog to digital converter (DAC) **264**.

In an example of operation, the encoder **222** of the transmitter **112** receives information bits **201** of data (e.g., video data, audio data, text, graphics, voice data, etc.). The encoder **222** encodes (in accordance with one or more ECC coding functions, FEC encoding functions, or other encoding functions) a number of the information bits into a plurality of encoded bits **202**. For example, the encoder **222** breaks the data into 4-bit data blocks and encodes each 4-bit data block separately to produce the plurality of encoded bits (e.g., an encoded data block), which includes more bits than the data block (e.g., 5 or more bits). As such, the encoder is outputting a sequence of encoded bits; one sequence for each data block.

The symbol mapper **224** maps the encoded bits (of one encoded data block) to a constellation point of a constellation map. The constellation map includes a plurality of constellation points and null points that are arranged to one or more patterns that reduce transmission errors and/or lower SNR while achieving a desired BER of a communication channel. The symbol mapper **224** outputs a sequence of symbols **203** (e.g., constellation points corresponding to mapped encoded data blocks) to the transmit driver **230**.

The DAC **232** converts the sequence of symbols into a continuous-time transmit signal **204**. The transmit filter **234** (e.g., channel filter, bandpass filter, notch filter, low pass filter, high pass filter, etc.) filters the signal **204** to produce a filtered, continuous-time transmit (TX) signal **205**. The transmitter **112** transmits, via the communication channel **199**, the filtered TX signal **205** to the receiver **112** of the other communication device **120**.

Within the receiver **122**, the receive filter **262** (e.g., channel filter, bandpass filter, notch filter, low pass filter, high pass filter, etc.) filters the continuous-time receive signal **206**. An analog to digital converter (ADC) **264** converts the continuous-time receive signal **206** into discrete-time receive signals **208**. The metric generator or symbol de-mapper **270** calculates metrics **209** (e.g., on either a symbol and/or bit basis, which may be log-likelihood ratios (LLRs) or other types of metrics). For example, metrics **209** may be viewed as estimated constellation points on the constellation map. The decoder **280** (which essential performs the inverse of the encoder) interprets the metrics **209** to create estimates of the information bits **210**.

FIG. **3** illustrates embodiments **300** of encoding and symbol mapping and symbol de-mapping and decoding. This diagram may be viewed as including processing module **280***a* and processing module **280***b* such as may be implemented in a communication device **110**, **120** that includes both the encoding and decoding functions. In particular, the processing module **280** is configured to include the encoder **222**, the symbol mapper **224**, the metric generator or symbol de-mapper **270**, and the decoder **280**. The functions of these elements are as previously described. In additional to the functionality as previously described, this embodiment provides a bypass of the encoder **222** and the decoder **280**. As such, for certain applications, the information bits may be directly mapped to constellation points on the constellation map.

Also, it is noted that any such desired modulation (e.g., constellation points with associated mapping/labeling of the constellation points therein) may be implemented in any of a variety of ways (e.g., look up table (LUT) [such that a symbol of bit label is mapped to a respective constellation point based on the LUT] in some form of memory, via real-time calculation using one or more processors [such as a digital signal processor (DSP)], etc. and/or any such combination of means. For example, some embodiments will store the modulation in a LUT and/or memory for relatively smaller sized constellations (e.g., including constellation points below some desired or predetermined value), and use real-time calculation to generate the modulation for relatively larger sized constellations (e.g., including constellation points equal to or above some desired or predetermined value). For example, relatively large sized constellations can require a relatively significant amount of memory, and real-time calculation may be more efficient in some embodiments.

FIG. **4** illustrates an embodiment **400** of conceptually altering a rectangle shaped constellation to achieve a cross shaped constellation. A conceptual rectangle-shaped constellation (e.g., one having more bit locations along one particular axis then along the other) includes subsets of constellation points arranged in a rectangular pattern. In this example, the subsets include a common subset **402**, a first subset **404**, a second subset **406**, a third subset **408**, and a fourth subset **410**. The first and second subsets **404** and **406** are on the left side of the rectangle shaped constellation map and the third and fourth subsets **408** and **410** are on the right side of the rectangle shaped constellation map. Note that each subset of constellation points includes two or more constellation points and may be square shaped or rectangle shaped.

The conceptual rectangle shaped constellation is transformed into the cross-shaped constellation by rearranging some of the subsets. In this example, the common subset **402** is positioned similarly, with respect to first and second axis (e.g., an I axis and a Q axis) in the cross-shaped constellation as it is in the rectangle shaped constellation. The first subset of the constellation points **404** is relocated from the left hand side of the rectangle shaped constellation to the bottom of the cross-shaped constellation; the second subset of the constellation points **406** is relocated from the left hand side of the rectangle shaped constellation to the top of the cross-shaped constellation; the third subset of the constellation points **408** is relocated from the right hand side of the rectangle shaped constellation to the top of the cross-shaped constellation; and the fourth subset of the constellation points **410** is relocated from the right hand side of the rectangle shaped constellation to the top of the cross-shaped constellation.

As an alternative, the orientation of the conceptual rectangle shaped constellation may be rotated ninety degrees such that there are more constellation points along the Q axis than the I axis. In this alternative, the cross shaped constellation would be similarly rotated.

In one embodiment, a modification of the mapping performed in accordance with the G.hn communication standard, specifically, Step 3 in Section 7.1.4.3.1.2 Constellations for odd number of bits of Rec. ITU-T G.9960 (December 2011), which includes the following formulas:

$$|Q'|=|I|-2s, \text{ and } \text{sign}(Q')=\text{sign}(I);$$

$$|I'|=M_Q-|Q|, \text{ and } \text{sign}(I')=\text{sign}(Q).$$

Modification of these respective formulas by their replacement as follows:

if ($|Q|<2s$) then

$$|I'|=|I|-4s, \text{ and } \text{sign}(I')=\text{sign}(I);$$

$$|Q'|=|Q|+4s, \text{ and } \text{sign}(Q')=\text{sign}(Q).$$

else

$|I'|=M_I-|I|$, and $\text{sign}(I')=\text{sign}(I)$;

$|Q'|=M_I-|Q|$, and $\text{sign}(Q')=\text{sign}(Q)$.

endif

will result in the modification of the rectangle-shaped constellation to generate the cross-shaped constellation in accordance with various embodiments and/or their equivalents herein.

In general, the conceptual conversion of a rectangle shaped constellation into a shape as shown herein may be performed in accordance with any desired symbols or bit labels having an odd number of bits therein (e.g., 3, 5, 7, 9, 11, etc.). For example, a given symbol or bit label can include an odd number of encoded bits, N, where N is an odd-valued integer, and the modulation can would then include $Y=2^N$ constellation points (e.g., if N=5, then Y=32; if N=7, then Y=128; etc.).

FIG. **5** illustrates an example **500** of 32 QAM constellation map (or just constellation) in accordance with the present disclosure. The constellation includes a plurality of constellation points and null points at the corners (e.g., a null may be viewed as a location that does not include a constellation point). FIG. **5** further illustrates a conceptual rectangle shaped constellation that includes four rows and eight columns centered about the origin of the intersection of a first and second axis. The axis forms quadrants; each quadrant including eight constellation points.

The conceptual rectangle shaped constellation includes a common subset of constellation points, a first subset of constellation points, a second subset of constellation points, a third subset of constellation points, and a fourth subset of constellation points. The first subset includes constellation points corresponding symbols 01 000 and 11 000; the second subset includes constellation points corresponding to symbols 10 000 and 00 000; the third subset includes constellation points corresponding to symbols 01 001 and 11 001; the fourth subset includes constellation points corresponding to symbols 10 001 and 00 001; the common subset includes the remaining constellation points.

The conceptual rectangle shaped constellation is conceptually modified to the desired constellation by moving the first, second, third, and fourth subsets of constellation points as shown. The resulting constellation has a cross shape with null points in the corners. In effect, by relocating constellation points of a conceptual rectangle shaped constellation into the desired shape, the collective magnitude of the vector of the relocated constellation points is less than the collective magnitudes of the vectors if not relocated. Further, the new pattern maintains a one-bit difference between symbols of vertical and horizontal adjacent constellation points.

The new pattern of the constellation also has symmetry about the axis. For example, the pattern of constellation points and null points of the first quadrant (e.g., upper left quadrant on the figure) is the mirror image about the vertical axis as the pattern of constellation points and null points of the second quadrant (e.g., the upper right quadrant on the figure). In this example, the first quadrant also a mirrored pattern of constellation points and null points, about the horizontal axis, as the pattern of the third quadrant (e.g., the lower left quadrant of the figure). As a further example, the second quadrant has a mirrored pattern of constellation points and null points, about the horizontal axis, as the pattern of the fourth quadrant (e.g., the lower right quadrant of the figure).

FIG. **6** illustrates an example **600** of 128 QAM constellation in accordance with the present disclosure. In this example, the constellation includes 128 constellation points (one for each symbol in the range of 0 to 2^8) and sixteen null points. The concept of modifying a rectangle shaped constellation into the present constellation is the same as discussed with reference to FIGS. **4** and **5**, with a difference being the number of constellation points in a subset. In this example, the first subset includes eight constellation points (111 0000, 111 1000, 101 1000, 101 000, 011 0000, 011 1000, 001 1000, and 001 0000), and so on.

The 128 QAM constellation has a cross shaped pattern of constellation points with null points in the corners and, by relocating constellation points of a conceptual rectangle shaped constellation into the desired shape, the magnitude of the vector of the relocated constellation points is most often less than the magnitude of the vector if not relocated. Further, the new pattern maintains a one-bit difference between symbols of vertical and horizontal adjacent constellation points and has symmetry from quadrant to quadrant about the vertical and/or horizontal axis.

FIG. **6**A illustrates another example **601** of a 128 QAM constellation in accordance with the present disclosure. In this example, the constellation includes 128 constellation points (one for each symbol in the range of 0 to 2^8), a plurality of null points, and the modification of the conceptual rectangle shaped constellation is somewhat different. As with FIG. **6**, the conceptual rectangle shaped constellation includes the first, second, third, fourth, and common subsets of constellation points. In this example, however, the first, second, third, and fourth subsets are relocated differently.

In particular, the subsets are relocated to maintain the 1 bit difference between symbols of horizontally and vertically adjacent constellation points and collectively reduce the magnitude of the vector for the relocated constellation points with respect to the rectangle shaped constellation. For example, the constellation points of the first subset **404** are relocated as shown. In a particular example, constellation point corresponding to symbol 111 1000 is shown in row 6, column 3 of quadrant 1 (from the origin) in FIG. **6** and is shown in row 7, column 2 of quadrant 1 in FIG. **6**A. Further, the constellation point corresponding to symbol 111 0000 is shown in row 6, column 4 of quadrant 1 of FIG. **6** and in row 7, column 1 of quadrant 1 of FIG. **6**A. Note that there are 17 null points in each of the four corners of a square outline encompassing the 128 QAM constellation.

FIG. **7** is a diagram illustrating an embodiment of a method **700** for operating one or more wireless communication devices. One implementation of the method **700** operates by performing only the operations of the blocks **710** and **720**. Another implementation of the method **700** operates by performing only the operations of the blocks **710**, **720**, and **722**. Yet another implementation of the method **700** operates by performing operations of all of the blocks therein.

Referring to the diagram, the method **700** begins by encoding at least one information bit to generate at least one encoded bit, as shown in a block **710**.

The method **700** continues by operating a symbol mapper (e.g., of communication device) to map at least one symbol or bit label including the at least one encoded bit to a cross-shaped constellation, as shown in a block **720**.

With respect to the cross-shaped constellation employed, it may be viewed as being derived from a rectangle-shaped constellation. For example, the cross-shaped constellation derived from a rectangle-shaped constellation having a plurality of constellation points including subsets of the plurality of constellation points along either a left hand side or a right hand side of the rectangle-shaped constellation such that a first of the subsets of the plurality of constellation points relocated to be along a top of the cross-shaped constellation and a second of the subsets of the plurality of constellation

points relocated to be along a bottom of the cross-shaped constellation, as shown in a block **722**. This transformation may alternatively be viewed as generating a constellation that includes a plurality of constellation points and a set of null points orientated with respect to at least one of a first axis and a second axis, and such that quadrants of the constellation, from quadrant to quadrant along at least one of the first axis and the second axis, have a mirroring pattern of constellation points of the plurality of constellation points and of null points of the set of null points.

In certain embodiments, the method **700** then operates by operating a transmit driver of the communication device to process at least one discrete-valued modulation symbol (e.g., generated by the symbol mapper) to generate a continuous-time signal, as shown in a block **730**.

Also, in certain embodiments, the method **700** continues by transmitting the continuous-time signal to at least one additional communication device via at least one communication channel, as shown in a block **740**.

FIG. **8** is a diagram illustrating another embodiment of a method **800** for operating one or more wireless communication devices. Referring to method **800** of FIG. **8**, one implementation of the method **800** operates by performing only the operations of the blocks **830** and **840**. Another implementation of the method **800** operates by performing only the operations of the blocks **830**, **832**, and **840**. Yet another implementation of the method **800** operates by performing operations of all of the blocks therein.

Referring to the diagram, the method **800** begins by receiving a continuous-time signal from at least one additional communication device via at least one communication channel (e.g., via at least one input and/or communication interface of a communication device), as shown in a block **810**.

The method **800** continues by operating an analog front end (AFE) of the communication device to process the continuous-time signal to generate a discrete-time signal, as shown in a block **820**.

The method **800** then operates by operating a symbol demapper of the communication device to process the discrete-time signal based on a cross-shaped constellation (e.g., to generate symbol and/or bit metrics), as shown in a block **830**.

With respect to the cross-shaped constellation employed, it may be viewed as being derived from a rectangle-shaped constellation. For example, the cross-shaped constellation derived from a rectangle-shaped constellation having a plurality of constellation points including subsets of the plurality of constellation points along either a left hand side or a right hand side of the rectangle-shaped constellation such that a first of the subsets of the plurality of constellation points relocated to be along a top of the cross-shaped constellation and a second of the subsets of the plurality of constellation points relocated to be along a bottom of the cross-shaped constellation, as shown in a block **832**.

The method **800** continues by performing decoding processing based on the symbol and/or bit metrics to generate at least one estimate of an information bit encoded within the continuous-time signal, as shown in a block **840**.

The present invention has been described herein with reference to at least one embodiment. Such embodiment(s) of the present invention have been described with the aid of structural components illustrating physical and/or logical components and with the aid of method steps illustrating the performance of specified functions and relationships thereof. The boundaries and sequence of these functional building blocks and method steps have been arbitrarily defined herein for convenience of description. Alternate boundaries and sequences can be defined so long as the specified functions and relationships are appropriately performed. Any such alternate boundaries or sequences are thus within the scope and spirit of the claims that follow. Further, the boundaries of these functional building blocks have been arbitrarily defined for convenience of description. Alternate boundaries could be defined as long as the certain significant functions are appropriately performed. Similarly, flow diagram blocks may also have been arbitrarily defined herein to illustrate certain significant functionality. To the extent used, the flow diagram block boundaries and sequence could have been defined otherwise and still perform the certain significant functionality. Such alternate definitions of both functional building blocks and flow diagram blocks and sequences are thus within the scope and spirit of the claimed invention. One of average skill in the art will also recognize that the functional building blocks, and other illustrative blocks, modules and components herein, can be implemented as illustrated or by discrete components, application specific integrated circuits, processors executing appropriate software and the like or any combination thereof.

As may also be used herein, the terms "processing module," "processing circuit," "processing circuitry," and/or "processing unit" may be a single processing device or a plurality of processing devices. Such a processing device may be a microprocessor, micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on hard coding of the circuitry and/or operational instructions. The processing module, module, processing circuit, and/or processing unit may be, or further include, memory and/or an integrated memory element, which may be a single memory device, a plurality of memory devices, and/or embedded circuitry of another processing module, module, processing circuit, and/or processing unit. Such a memory device may be a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, cache memory, and/or any device that stores digital information. Note that if the processing module, module, processing circuit, and/or processing unit includes more than one processing device, the processing devices may be centrally located (e.g., directly coupled together via a wired and/or wireless bus structure) or may be distributedly located (e.g., cloud computing via indirect coupling via a local area network and/or a wide area network). Further note that if the processing module, module, processing circuit, and/or processing unit implements one or more of its functions via a state machine, analog circuitry, digital circuitry, and/or logic circuitry, the memory and/or memory element storing the corresponding operational instructions may be embedded within, or external to, the circuitry comprising the state machine, analog circuitry, digital circuitry, and/or logic circuitry. Still further note that, the memory element may store, and the processing module, module, processing circuit, and/or processing unit executes, hard coded and/or operational instructions corresponding to at least some of the steps and/or functions illustrated in one or more of the Figures. Such a memory device or memory element can be included in an article of manufacture.

As may be used herein, the terms "substantially" and "approximately" provides an industry-accepted tolerance for its corresponding term and/or relativity between items. Such an industry-accepted tolerance ranges from less than one percent to fifty percent and corresponds to, but is not limited to, component values, integrated circuit process variations, temperature variations, rise and fall times, and/or thermal

noise. Such relativity between items ranges from a difference of a few percent to magnitude differences. As may also be used herein, the term(s) "configured to", "operably coupled to", "coupled to", and/or "coupling" includes direct coupling between items and/or indirect coupling between items via an intervening item (e.g., an item includes, but is not limited to, a component, an element, a circuit, and/or a module) where, for an example of indirect coupling, the intervening item does not modify the information of a signal but may adjust its current level, voltage level, and/or power level. As may further be used herein, inferred coupling (i.e., where one element is coupled to another element by inference) includes direct and indirect coupling between two items in the same manner as "coupled to". As may even further be used herein, the term "configured to", "operable to", "coupled to", or "operably coupled to" indicates that an item includes one or more of power connections, input(s), output(s), etc., to perform, when activated, one or more its corresponding functions and may further include inferred coupling to one or more other items. As may still further be used herein, the term "associated with", includes direct and/or indirect coupling of separate items and/or one item being embedded within another item.

Unless specifically stated to the contra, signals to, from, and/or between elements in a figure of any of the figures presented herein may be analog or digital, continuous time or discrete time, and single-ended or differential. For instance, if a signal path is shown as a single-ended path, it also represents a differential signal path. Similarly, if a signal path is shown as a differential path, it also represents a single-ended signal path. While one or more particular architectures are described herein, other architectures can likewise be implemented that use one or more data buses not expressly shown, direct connectivity between elements, and/or indirect coupling between other elements as recognized by one of average skill in the art.

The term "module" is used in the description of one or more of the embodiments. A module includes a processing module, a functional block, hardware, and/or software stored on memory for performing one or more functions as may be described herein. Note that, if the module is implemented via hardware, the hardware may operate independently and/or in conjunction with software and/or firmware. As also used herein, a module may contain one or more sub-modules, each of which may be one or more modules.

While particular combinations of various functions and features of the one or more embodiments have been expressly described herein, other combinations of these features and functions are likewise possible. The present disclosure of an invention is not limited by the particular examples disclosed herein and expressly incorporates these other combinations.

What is claimed is:

1. A communication device comprising:

an encoder configured to encode at least one information bit to generate a plurality of encoded bits; and

a symbol mapper configured to map the plurality of encoded bits to a constellation point of a constellation, wherein the constellation includes a plurality of constellation points and a set of null points orientated with respect to at least one of a first axis or a second axis, wherein quadrants of the constellation, from quadrant to quadrant along at least one of the first axis or the second axis, have a mirroring pattern of constellation points of the plurality of constellation points and of null points of the set of null points, and wherein the set of null points corresponds to a plurality of locations in the constellation not including constellation points.

2. The communication device of claim **1**, wherein the plurality of encoded bits comprises:

an odd number of encoded bits, N, where N is an odd-valued integer; and

the plurality of constellation points includes 2^N constellation points.

3. The communication device of claim **1**, wherein the constellation comprises:

along the first axis or along the second axis, an adjacent constellation point of the constellation represents a one-bit difference of encoded bits with respect to the plurality of encoded bits.

4. The communication device of claim **1** further comprising:

a transmit driver configured to transmit a continuous-time signal that is representative of at least one of the plurality of constellation points.

5. The communication device of claim **1** further comprising a transmitter and a receiver for communication within at least one of a satellite communication system, a wireless communication system, a wired communication system, a fiber-optic communication system, or a mobile communication system.

6. A communication device comprising:

an encoder configured to encode at least one information bit to generate at least one encoded bit; and

a symbol mapper configured to map at least one symbol or bit label that is representative of the at least one encoded bit to a constellation point of a cross-shaped constellation, wherein the cross-shaped constellation is based on a rectangle-shaped constellation having a plurality of constellation points that includes subsets of the plurality of constellation points along at least one of a left hand side or a right hand side of the rectangle-shaped constellation, wherein a first subset of the subsets of the plurality of constellation points is relocated to a top of the cross-shaped constellation and a second subset of the subsets of the plurality of constellation points is relocated to a bottom of the cross-shaped constellation.

7. The communication device of claim **6**, wherein:

the first and second subsets being on the left hand side of the rectangle-shaped constellation; and

the right hand side of the rectangle-shaped constellation including a third subset and a fourth subset of the subsets of the plurality of constellation points, wherein the at least one additional subsets of the plurality of constellation points, such that:

the third subset is relocated to the top of the cross-shaped constellation; and

the fourth subset is relocated to the bottom of the cross-shaped constellation.

8. The communication device of claim **6**, wherein the encoder comprising a low density parity check (LDPC) code encoder.

9. The communication device of claim **6**, wherein the at least one symbol or bit label comprising:

an odd number of encoded bits, N, where N is an odd-valued integer; and

the plurality of constellation points includes 2^N constellation points.

10. The communication devices of claim **6**, wherein the rectangle-shaped constellation further comprising at least one additional subset of constellation points, located between the left hand side or the right hand side of the rectangle-shaped constellation, that are also included and commonly located within the cross-shaped constellation.

11. The communication device of claim 6 further comprising:

a transmit driver configured to transmit a continuous-time signal that is representative of the constellation point.

12. The communication device of claim 6 further comprising:

an input configured to receive a continuous-time signal that represents a transmitted constellation point;

an analog front end (AFE) configured to process the continuous-time signal to generate a discrete-time signal; and

a symbol de-mapper configured to process the discrete-time signal based on the cross-shaped constellation to identify the transmitted constellation point.

13. The communication device of claim 6 further comprising:

a transmitter and receiver for communication within at least one of a satellite communication system, a wireless communication system, a wired communication system, a fiber-optic communication system, or a mobile communication system.

14. A method for execution by a communication device, the method comprising:

encoding at least one information bit to generate at least one encoded bit; and

operating a symbol mapper of the communication device to map at least one symbol or bit label that includes the at least one encoded bit to a constellation, wherein the constellation includes a plurality of constellation points and a set of null points orientated with respect to at least one of a first axis or a second axis, wherein quadrants of the constellation, from quadrant to quadrant along at least one of the first axis or the second axis, have a mirroring pattern of constellation points of the plurality of constellation points and of null points of the set of null points, and wherein the set of null points corresponds to a plurality of locations in the constellation that not including constellation points.

15. The method of claim 14, wherein:

the constellation is a cross-shaped constellation that is based on a rectangle-shaped constellation having the plurality of constellation points, wherein the plurality of constellation points includes subsets of the plurality of constellation points along at least one of a left hand side or a right hand side of the rectangle-shaped constellation, wherein a first subset of the subsets of the plurality of constellation points is relocated to a top of the cross-shaped constellation and a second subset of the subsets of the plurality of constellation points is relocated to a bottom of the cross-shaped constellation;

the first and second subsets being on the left hand side of the rectangle-shaped constellation; and

the right hand side of the rectangle-shaped constellation including a third subset and a fourth subset of the subsets of the plurality of constellation points, wherein the at least one additional subsets of the plurality of constellation points, such that:

the third subset is relocated to the top of the cross-shaped constellation; and

the fourth subset is relocated to the bottom of the cross-shaped constellation.

16. The method of claim 14 further comprising:

performing low density parity check (LDPC) code encoding to encode the at least one information bit to generate an LDPC codeword that includes the at least one encoded bit.

17. The method of claim 14, wherein the at least one symbol or bit label comprising:

an odd number of encoded bits, N, where N is an odd-valued integer; and

the plurality of constellation points includes 2^N constellation points.

18. The method of claim 14, wherein:

the constellation is a cross-shaped constellation that is based on a rectangle-shaped constellation having the plurality of constellation points;

the plurality of constellation points includes subsets of the plurality of constellation points along at least one of a left hand side or a right hand side of the rectangle-shaped constellation; and

the rectangle-shaped constellation further comprising at least one additional subset of constellation points, located between the left hand side or the right hand side of the rectangle-shaped constellation, that are also included and commonly located within the cross-shaped constellation.

19. The method of claim 14 further comprising:

transmitting a continuous-time signal that is representative of at least one of the plurality of constellation points.

20. The method of claim 14, wherein the communication device is operative within at least one of a satellite communication system, a wireless communication system, a wired communication system, a fiber-optic communication system, and or a mobile communication system.

* * * * *